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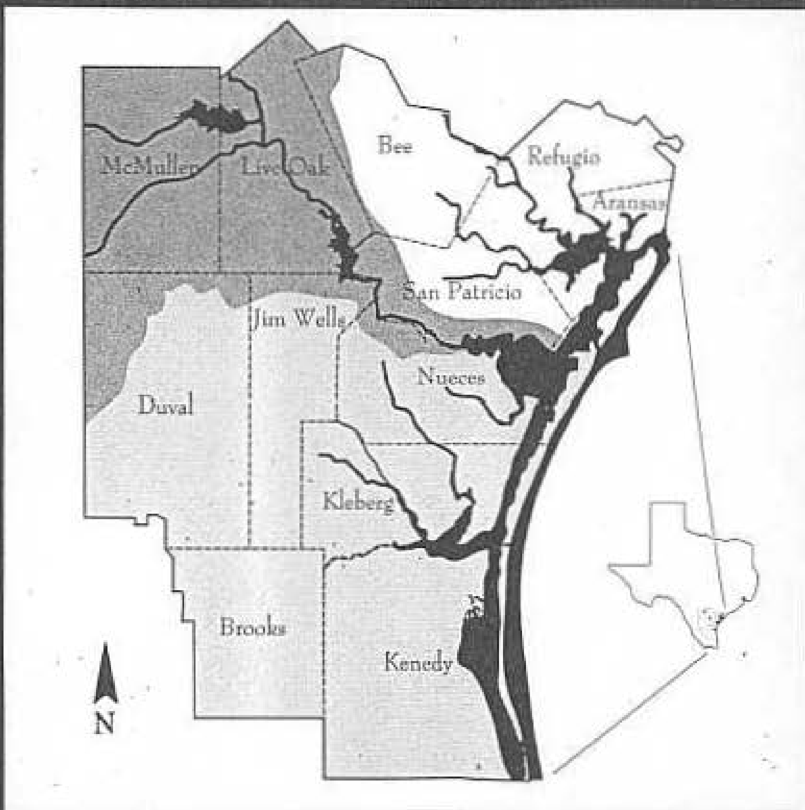
C... tatus and Historical Trends of ... uarine Living Resources within th... s Christi Bay National Estuary Program Study Area

Volume 1 of 4



Corpus Christi Bay National Estuary Program

CCBNEP-06A January 1996

Volume 1

Current Status and Historical Trends of the Estuarine Living Resources within the Corpus Christi Bay National Estuary Program Study Area

John W. Tunnell, Jr. and Quenton. R Dokken
Co-principal Investigators and Editors

and

Elizabeth H. Smith and Kim Withers
Associate Editors

Center for Coastal Studies
Texas A&M University-Corpus Christi
6300 Ocean Drive
Corpus Christi, Texas 78412

January 1996

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CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM

The Corpus Christi Bay National Estuary Program (CCBNEP) is a four-year, community based effort to identify the problems facing the bays and estuaries of the Coastal Bend, and to develop a long-range, Comprehensive Conservation and Management Plan. The Program's fundamental purpose is to protect, restore, or enhance the quality of water, sediments, and living resources found within the 600 square mile estuarine portion of the study area.

The Coastal Bend bay system is one of 28 estuaries that have been designated as an **Estuary of National Significance** under a program established by the United States Congress through the Water Quality Act of 1987. This bay system was so designated in 1992 because of its benefits to Texas and the nation. For example:

- Corpus Christi Bay is the gateway to the nation's seventh largest port, and home to the third largest refinery and petrochemical complex. The Port generates over $1 billion of revenue for related businesses, more than $60 million in state and local taxes, and more than 31,000 jobs for Coastal Bend residents.
- The bays and estuaries are famous for their recreational and commercial fisheries production. A study by Texas Agricultural Experiment Station in 1987 found that these industries, along with other recreational activities, contributed nearly $760 million to the local economy, with a statewide impact of $1.3 billion, that year.
- Of the approximately 100 estuaries around the nation, the Coastal Bend ranks fourth in agricultural acreage. Row crops -- cotton, sorghum, and corn -- and livestock generated $480 million in 1994 with a statewide economic impact of $1.6 billion.
- There are over 2600 documented species of plants and animals in the Coastal Bend, including several species that are classified as endangered or threatened. Over 400 bird species live in or pass through the region every year, making the Coastal Bend one of the premier bird watching spots in the world.

The CCBNEP is gathering new and historical data to understand environmental status and trends in the bay ecosystem, determine sources of pollution, causes of habitat declines and risks to human health, and to identify specific management actions to be implemented over the course of several years. The 'priority problems' under investigation include:

- altered freshwater inflow into bays and estuaries
- loss of wetlands and estuarine habitats
- declines in living resources
- degradation of water quality
- altered estuarine circulation
- bay debris
- selected public health issues

The **COASTAL BEND BAYS PLAN** that will result from these efforts will be the beginning of a well-coordinated and goal-directed future for this regional resource.

STUDY AREA DESCRIPTION

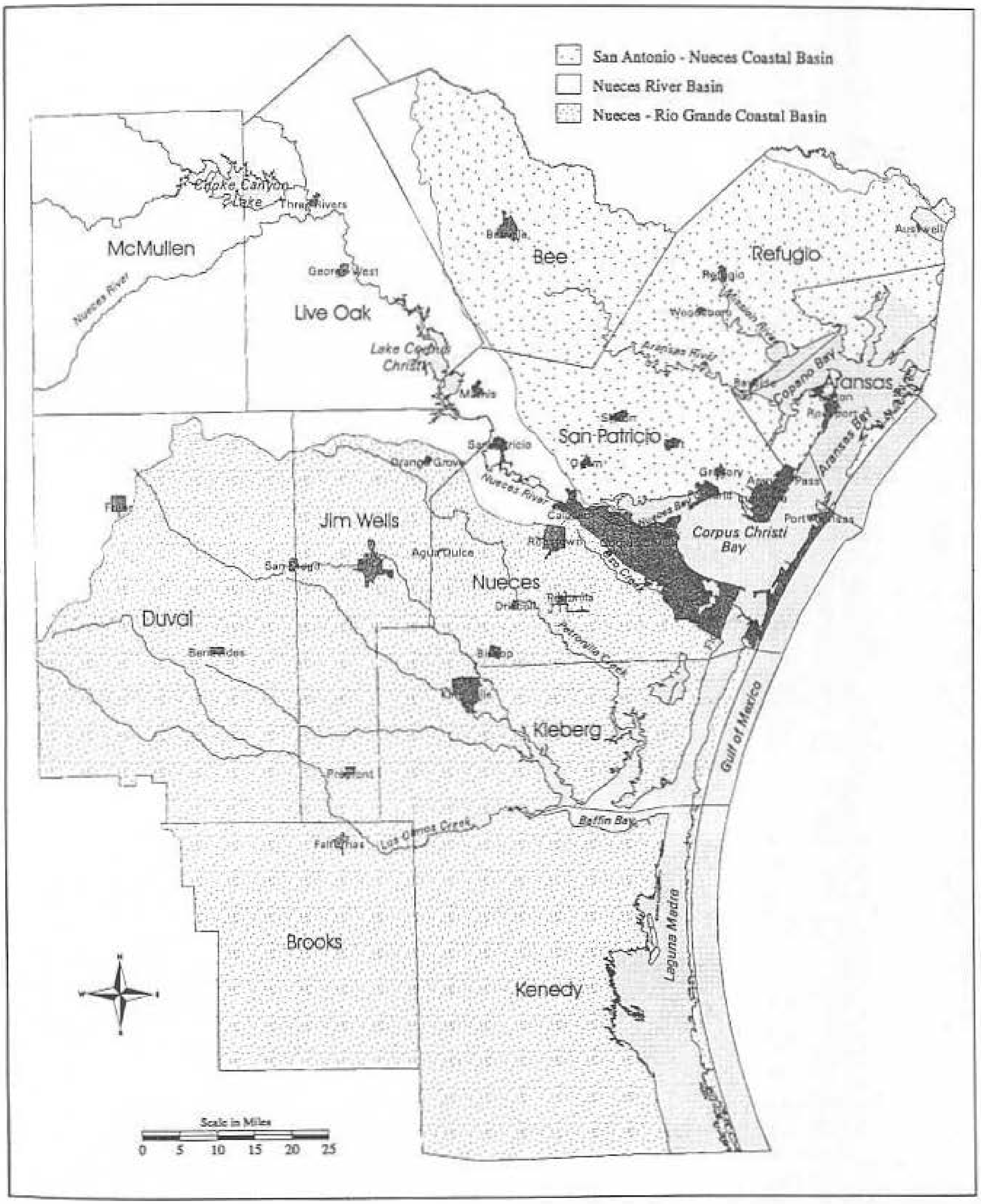
The CCBNEP study area includes three of the seven major estuary systems of the Texas Gulf Coast. These estuaries, the Aransas, Corpus Christi, and Upper Laguna Madre are shallow and biologically productive. Although connected, the estuaries are biogeographically distinct and increase in salinity from north to south. The Laguna Madre is unusual in being only one of three hypersaline lagoon systems in the world. The study area is bounded on its eastern edge by a series of barrier islands, including the world's longest -- Padre Island.

Recognizing that successful management of coastal waters requires an ecosystems approach and careful consideration of all sources of pollutants, the CCBNEP study area includes the 12 counties of the Coastal Bend: Refugio, Aransas, Nueces, San Patricio, Kleberg, Kenedy, Bee, Live Oak, McMullen, Duval, Jim Wells, and Brooks.

This region is part of the Gulf Coast and South Texas Plain which are characterized by gently sloping plains. Soils are generally clay to sandy loams. There are three major rivers (Aransas, Mission, and Nueces), few natural lakes, and two reservoirs (Lake Corpus Christi and Choke Canyon Reservoir) in the region. The natural vegetation is a mixture of coastal prairie and mesquite chaparral savanna. Land use is largely devoted to rangeland (61%), with cropland and pastureland (27%) and other mixed uses (12%)

The region is semi-arid with a subtropical climate (average annual rainfall varies from 25 to 38 inches); rainfall is highly variable from year to year. Summers are hot and humid, while winters are generally mild with occasional freezes. Hurricanes and tropical storms periodically affect the region.

On the following page is a regional map showing the three bay systems that comprise the CCBNEP study area.



The Corpus Christi Bay National Estuary Program Study Area.

PREFACE

The summarization and analysis of the living resources of the Corpus Christi Bay National Estuary Program (CCBNEP) study area has been a rewarding, yet almost overwhelming task. However, now that a framework for the 3,178 species, eight major habitats, 49 protected species, and an introduced species is intact, it should become a standard resource tool for managers and scientists alike who deal with estuarine living resources within the Texas Coastal Bend. For resource managers, it should serve as a status reference of what is currently known, and to scientists, a challenge of what still needs to be done in areas of little or no information.

The overall organization and ecosystem approach of this review is presented as follows: the physical setting; the species; the habitats; the target organisms (i.e. species of concern, and trend-analyzed species); the probable causes of noted trends; and finally, the information gaps that have been identified.

Although the length of this report (1,442 pages in four volumes) is somewhat overwhelming, a complete review and presentation of current knowledge was necessary in order to address the many items requested in the original scope of work and to determine the probable causes and information gaps required in the contract. To make the document more "user friendly" to a broader audience, it is presented in four volumes, each of which can stand alone: Volume 1 (532 pages) - the main body and text; Volume 2 (496 pages) - the avian resources; Volume 3 (116 pages)- the project summary; and, Volume 4 (298 pages) - the species checklist, discussion, and conclusions. Each of these volumes have their own table of contents and literature cited. Likewise, within Volume 1, major sections can also be "pulled out" in chapter-type format (eg., habitat chapters, protected species, etc.) for use by the CCBNEP management conference members, or others.

Finally, there will undoubtedly be unintentional omissions discovered and refinements that will need to be made. Likewise, as new information becomes available, it should be incorporated, if this document is to remain as a working instrument for managers and researchers within the area. Consequently, it should be considered for review and update within five, but no longer than ten years.

John W. Tunnell, Jr.
January, 1996

EXECUTIVE SUMMARY

Living resources within the Corpus Christi Bay National Estuary Program (CCBNEP) study area are recognized as "unique and valuable resources which require protection" (CCBNEP, 1994a). The 121 km (75 mi) coastline of the Coastal Bend extends across three different bay systems and demonstrates a gradient of north to south climatic and aquatic conditions. The northern Mission-Aransas Estuary is brackish and subhumid, with salt marshes, oyster reefs, and fringing grass beds, while the southern Laguna Madre is hypersaline and semiarid, with vast expanses of shallow water and dense seagrass beds. The Nueces Estuary lies between these sparsely populated areas and supports the second largest human population on Texas estuarine shorelines.

The Living Resources Project involved a "holistic" or ecosystem level characterization of the living resources of the CCBNEP study area. This approach required a compilation of all known species of the area, as well as an examination of their habitats and their ecological roles or functioning. Protected species, designated as threatened or endangered, as well as introduced or exotic species were also characterized. During and after this information gathering and status characterization phase of the project, which included extensive review of published and unpublished literature, a final determination was made on the probable causes of recognized trends in populations of species, as well as information gaps about the species or their habitats.

A total of 3,178 species of plants and animals are listed in the checklist (Volume 4) of species from the CCBNEP study area estuarine waters and islands. The list includes 836 species of plants from seven different divisions, and 2,342 species of animals from 23 phyla. The largest group of plants is the diatoms, a phytoplankton group, with 341 species. Of the animals there are 1,418 invertebrates and 924 vertebrates. Eighty-five percent of all the invertebrates are found within three major phyla: Arthropoda (insects, crabs, shrimp, etc., 633 species), Annelida (segmented worms, with 289), and Mollusca (seashells, 230). Vertebrates are dominated by birds (494 species) and fish (234), with smaller numbers of reptiles (87), mammals (79), and amphibians (30).

Nationally and internationally renowned taxonomists who reviewed the prepared checklist, as well as recent literature on marine biodiversity, indicate that the CCBNEP species list should be considerably larger, probably as high as 4,000-5,000 species, or more. There is an obvious lack of information on many of the lesser-known or smaller sized groups of marine invertebrates and phytoplankton.

Predominant estuarine and island habitats within the CCBNEP study area include: Open Bay, Hard Substrates (jetties, groins, etc.), Oyster Reefs, Seagrass Meadows, Coastal Marshes, Tidal Flats, Barrier Islands, and Gulf Beaches. The Open Bay and Seagrass Meadow habitats have the largest number of species and have been the most studied. Oyster Reefs have many associated species but have been little studied, except for the oyster itself as a commercial commodity. Hard Substrates, Coastal Marshes, and Tidal Flats within the CCBNEP study area have not been studied much.

The Open Bay and Seagrass habitats have been impacted or altered primarily by dredging, channelization, and anthropogenic inputs. Oyster Reefs have been virtually eliminated from Nueces Bay by mudshell dredging, but they appear to be doing well in the Mission-Aransas

Estuary. Barrier Islands and Gulf Beaches are mostly affected by commercial development related to recreation and tourism and by oil spills.

Target organisms requiring special attention include fishery and avian resources (the only groups amenable to trend analysis), "protected species", and exotic or introduced species. Fishery resources were characterized via fishery dependent data acquired and analyzed from Texas Parks and Wildlife annual reports between 1972 and 1993, which revealed trend shifts of dockside commercial landings in shrimp and fish, but fairly consistent crab harvests. Shrimp harvest more than tripled from 1.8 million pounds in 1972 to 6.0 million pounds in 1993, while finfish harvest diminished. Changes in consumer demand and fishery regulations make it difficult to determine if changes harvest trends reflect changes in population abundances. Other trends in the commercial fishery, as well as recreational fishery are evident, and can usually be correlated with regulatory changes. Impacts to the fishery have been caused by opening and closing barrier island inlets, freezes, algal blooms, hypersalinity in the Laguna Madre, rainfall and floods, and hurricanes. Current management and conservation issues include harvest regulations, water management, finfish stock enhancement, and coastal zone management.

Avian resources of the CCBNEP study area include 494 species of birds, which were characterized utilizing three datasets for historical trends, the Texas Colonial Waterbird Counts, and two National Audubon Society Christmas Bird Counts: Aransas National Wildlife Refuge (38 years) and Corpus Christi (31 years). Although no overall trends for all birds collectively were identified, positive, negative, and neutral trends were determined for individual species. Over 400 trend analyses were run on the various species, and 101 species or groups are discussed individually with reasons for trends suggested. Colonial nesting waterbirds generally have decreasing nesting populations and stable or increasing winter populations. Loss and degradation of nesting habitats, and disturbance by humans are cited as causes for negative trends. Positive trends seen in most wintering waterfowl are generally attributed to increased national populations and available habitat. Stable to positive trends are seen with most shorebirds. Neotropical migrants within the CCBNEP study area mostly show stable to positive trends, although these data must be used with caution since the US Fish and Wildlife Services has declared major downward trends in many species nationally due to loss of habitat throughout their range.

Forty-nine species within the 12-county CCBNEP study area are Federally Listed as Endangered, Threatened, or Candidate species. Nineteen of these live in estuarine areas, including one plant (roughseed purslane), five sea turtles (Kemp's ridley, loggerhead, green, hawksbill, leatherback), one marsh turtle (Texas diamondback terrapin), one marsh snake (Gulf Coast salt marsh snake), and 11 birds (Brown Pelican, Reddish Egret, White-faced Ibis, Whooping Crane, American Peregrine Falcon, Piping Plover, Western Snowy Plover, Eskimo Curlew, Interior Least Tern, Loggerhead Shrike). The Whooping Crane and Brown Pelican show increasing population trends due to intensive management, while others are decreasing for various reasons, usually habitat degradation or loss. The status and trends of endangered, estuarine-obligate birds (Whooping Crane, Brown Pelican, Piping Plover, Interior Least Tern, and Eskimo Curlew) and sea turtles are summarized. In most cases, there is insufficient information to establish the status or trends of other species.

Of the exotic or introduced species, only the edible brown mussel is found in coastal waters, but the fire ant is also established on dredge material islands, occasionally impacting nesting success of colonial waterbirds.

The most widely cited probable causes of declining trends in certain species or groups of the CCBNEP study area are degradation and loss of habitat. Within the estuary, dredging has probably been the single largest cause of negative impact. However, some beneficial uses of dredging activity include lower salinity due to better circulation in the Laguna Madre and creation of colonial nesting waterbird habitat on dredge material islands. Most recently, habitat creation, restoration, or enhancement is being attempted with some dredge material. On the land agricultural, industrial, and municipal activities have caused the most degradation and loss of habitat. Increasing trends in human population levels in the Coastal Bend will likewise increase environmental stresses to natural populations, such as freshwater demand, increased liquid and solid waste, and habitat stresses.

Summarization of knowledge gaps indicates that more appears to be known about the physical environment than the biological component of the CCBNEP study area. Least is known about the ecological processes and linkages between systems, as well as the biology and taxonomy of the smaller-sized, lesser-known invertebrates and plants. Especially lacking are long-term datasets which are necessary for scientists and managers alike to monitor and identify trends in natural populations, other than birds and fish.

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LIST OF ACRONYMS

ABA	American Birding Association
ACOE (USACOE)	Army Corp of Engineers
ADU	American Ornithological Union
ANWR	Aransas National Wildlife Refuge
AWP	Aransas Wood Buffalo Population (Whooping Crane)
BEG	Bureau of Economic Geology
CBC	Christmas Bird Counts
CCBNEP	Corpus Christi Bay National Estuary Program
CCS	Center for Coastal Studies
CCW	Corpus Christi (Audubon Christmas Bird Count area)
CL	Carapace Length (in turtles)
CWS	Canadian Wildlife Service
EPA (USEPA)	Environmental Protection Acency
GIS	Geographic Information System
GIWW	Gulf Intracoastal Waterway
GLO	Texas General Land Office
HEART	Help Endangered Animals - - Ridley Turtles
INP	Instituto Nacional de Pesca (of Mexico)
IGW	Inshore Gulf Waters
MARPOL	Marine Pollution Treaty
MMRP	Marine Mammal Research Program
MOU	Memorandum of Understanding
NMFS	National Marine Fisheries Service
NPS	National Park Service
NOAA	National Oceanic and Atmospheric Administration
PA/CC	Port Aransas and Corpus Christi (regions)
PI	Principal Investigator
PINS	Padre Island National Seashore
QA	Quality Assurance
TAMU-CC	Texas A&M University - Corpus Christi
TCWS	Texas Colonical Waterbird Surveys
TDWR	Texas Department of Water Resources
TEAS	Texas Agricultural Experiment Station
TED	Turtle Excluder Device
TGFC	Texas Game and Fish Commission
TGFOC	Texas Game, Fish and Oyster Commission
TMMSN	Texas Marine Mammal Stranding Network
TNRCC	Texas Natural Resource Conservation Commission
TPWD	Texas Parks and Wildlife Department
TWC	Texas Water Commission
TWDB	Texas Water Development Board
USGS	United States Geological Survey
USFWS	United States Fish and Wildlife Service
USVI	United States Virgin Islands
UTMSI	University of Texas Marine Science Institute
YBP	Years Before Present

Table II.1. Major and minor bays and coastal lakes within the CCBNEP study area.

Aransas Estuary	Nueces Estuary	Baffin Bay-Laguna Madre
Aransas Bay	Corpus Christi Bay	Alazan Bay
Carlos Bay	Nueces Bay	Baffin Bay
Copano Bay	Oso Bay	Cayo del Grullo
Little Bay	Redfish Bay	Cayo del Infernillo
Mission Bay	Sunset Lake	Laguna Salada
Mission Lake		Upper Laguna Madre
*Mesquite Bay		
Port Bay		
South Bay		
Salt Lake		
St. Charles Bay		
Sundown Bay		
Swan Lake		

* Mesquite Bay is normally considered part of the San Antonio Bay system, but it is included herein as part of the CCBNEP study area.

To the north, Cedar Bayou lies between Matagorda Island and St. Joseph Island and connects Mesquite Bay, the most northerly part of the study area, with the Gulf of México. Historical records reveal Cedar Bayou has alternately opened and closed (Brown et al., 1976b).

At the most northerly and southerly ends of the CCBNEP study area, Mesquite Bay connects with Ayres Bay and the San Antonio Estuary; upper Laguna Madre connects via the Intracoastal Waterway through the Land-Cut to Redfish Bay in the lower Laguna Madre system. Details of each of the three estuarine systems within the CCBNEP study area are presented in Figure II.3 (Aransas Estuary), Figure II.4 (Nueces Estuary), and Figure II.5 (Upper Laguna Madre).

In terms of Pritchard's (1967) geomorphic classification of estuaries Copano, Nueces-Corpus Christi, and Baffin Bay, which are all perpendicular to the coastline, are coastal plain estuaries, composed of drowned river valleys. Aransas and Redfish bays and upper Laguna Madre are all considered bar-built estuaries and are oriented parallel to the coast. Pritchard (1967) defines an estuary as "a semi-enclosed coastal body of water having a free connection to the open sea and within which sea-water is measurably diluted with fresh water derived from land drainage". This definition applies well with the Mission-Aransas Estuary and the Nueces Estuary, but is not always

Table II.2. Areal coverage of major water bodies within CCBNEP study area at mean low water (from Diener, 1975).

System/Bay	mi^2	km^2	Acres	Hectares
Aransas Estuary	188.2	486.4	119,960	48,547
Aransas Bay	88	228	56,220	22,752
Copano Bay	65	169	41,740	16,892
Mesquite Bay	13	33	8,080	3,270
Mission Bay	6	15	3,760	1,522
Mission Lake	0.2	0.4	100	40
Port Bay	3	7	1,650	668
St. Charles Bay	13	34	8,410	3,403
Nueces Estuary	167	434	106,990	43,298
Corpus Christi Bay	115	299	73,820	29,874
Nueces Bay	29	75	18,470	7,475
Oso Bay	8	21	5,070	2,052
Redfish Bay	15	39	9,630	3,897
Baffin Bay/Upper Laguna Madre	159	410	101,370	41,022
Alazan Bay	22	56	13,860	5,609
Baffin Bay	50	129	31,870	12,897
Cayo del Grullo	7	18	4,470	1,809
Cayo del Infernillo	1	3	700	283
Laguna Salada	5	13	3,230	1,307
Upper Laguna Madre	74	191	47,240	19,117
CCBNEP Study Area	514.2	1,330.4	328,320	132,867

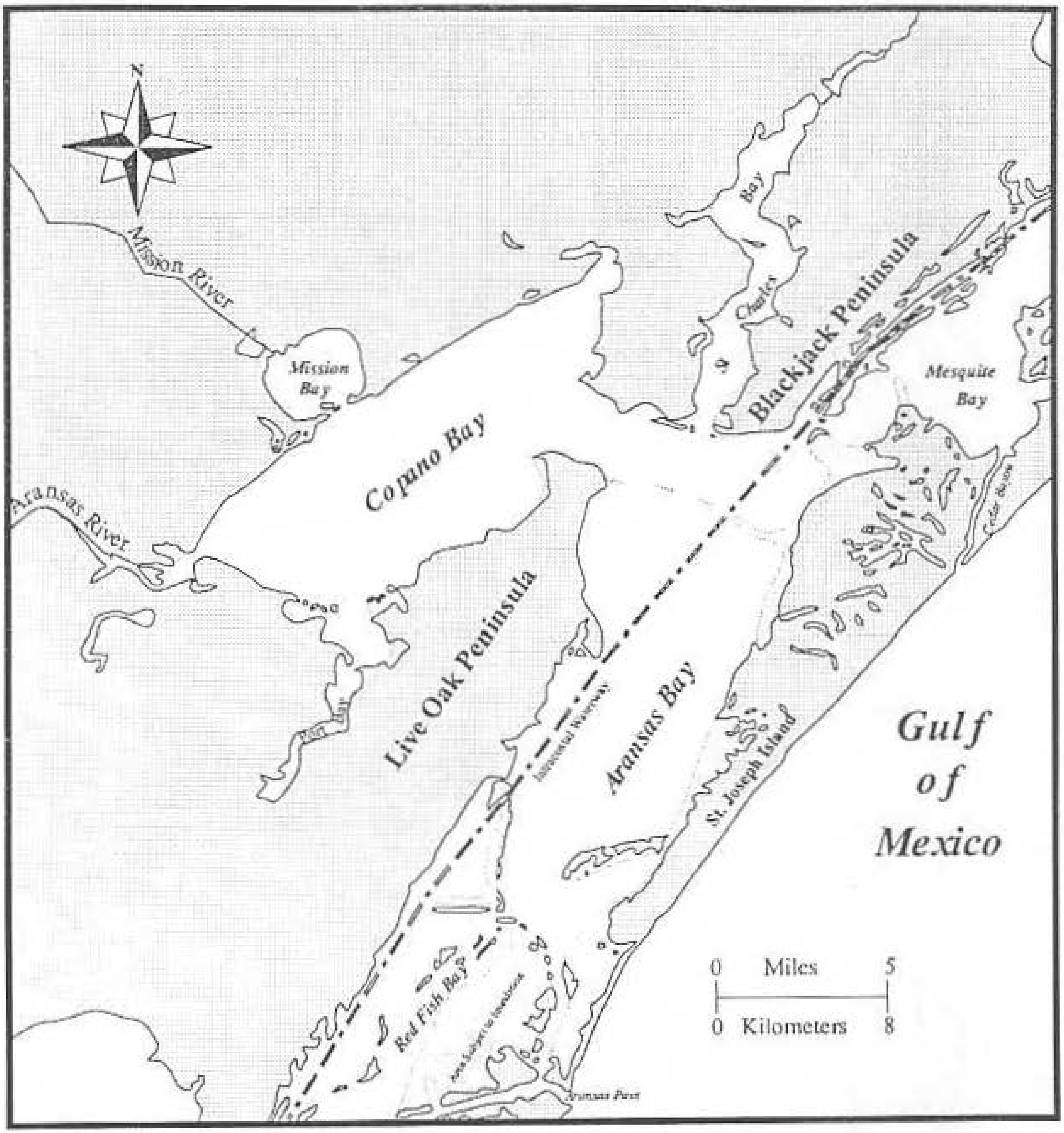

Fig. II.3. Mission-Aransas Estuary portion of CCBNEP study area.

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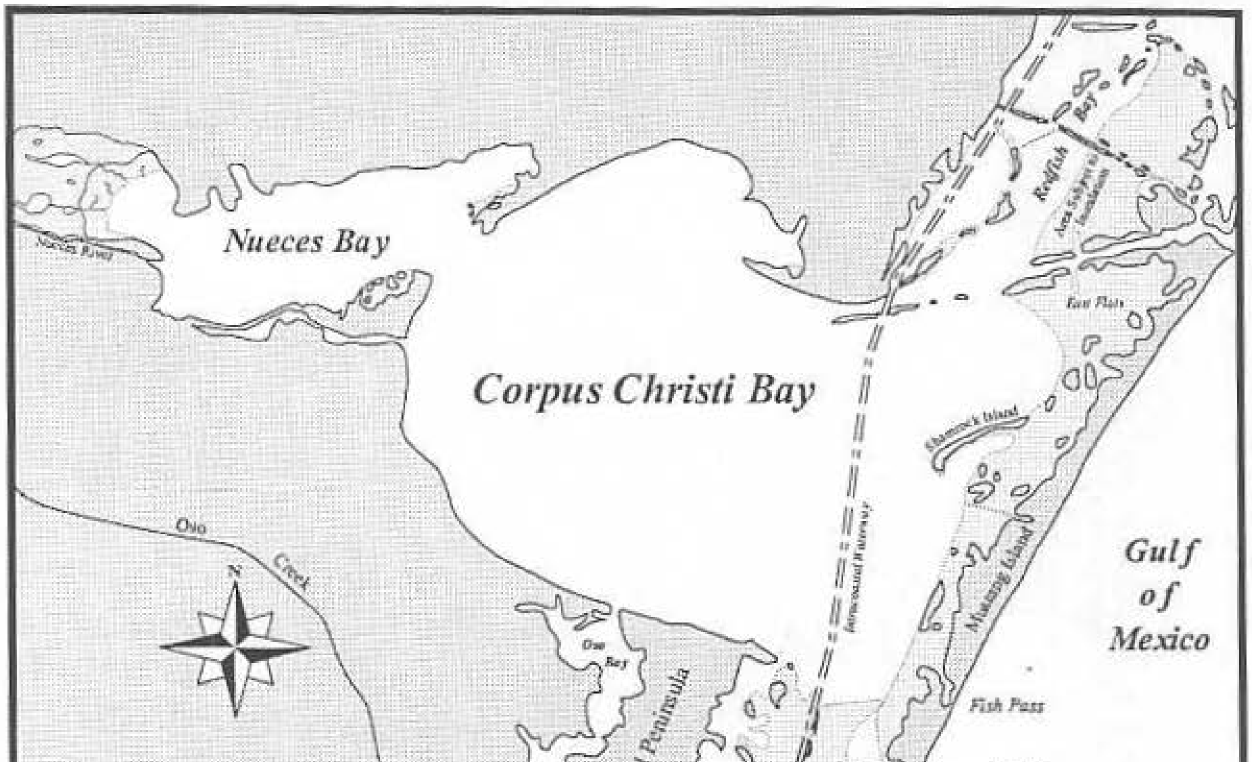

Fig. II.4. Nueces Estuary portion of CCBNEP study area.

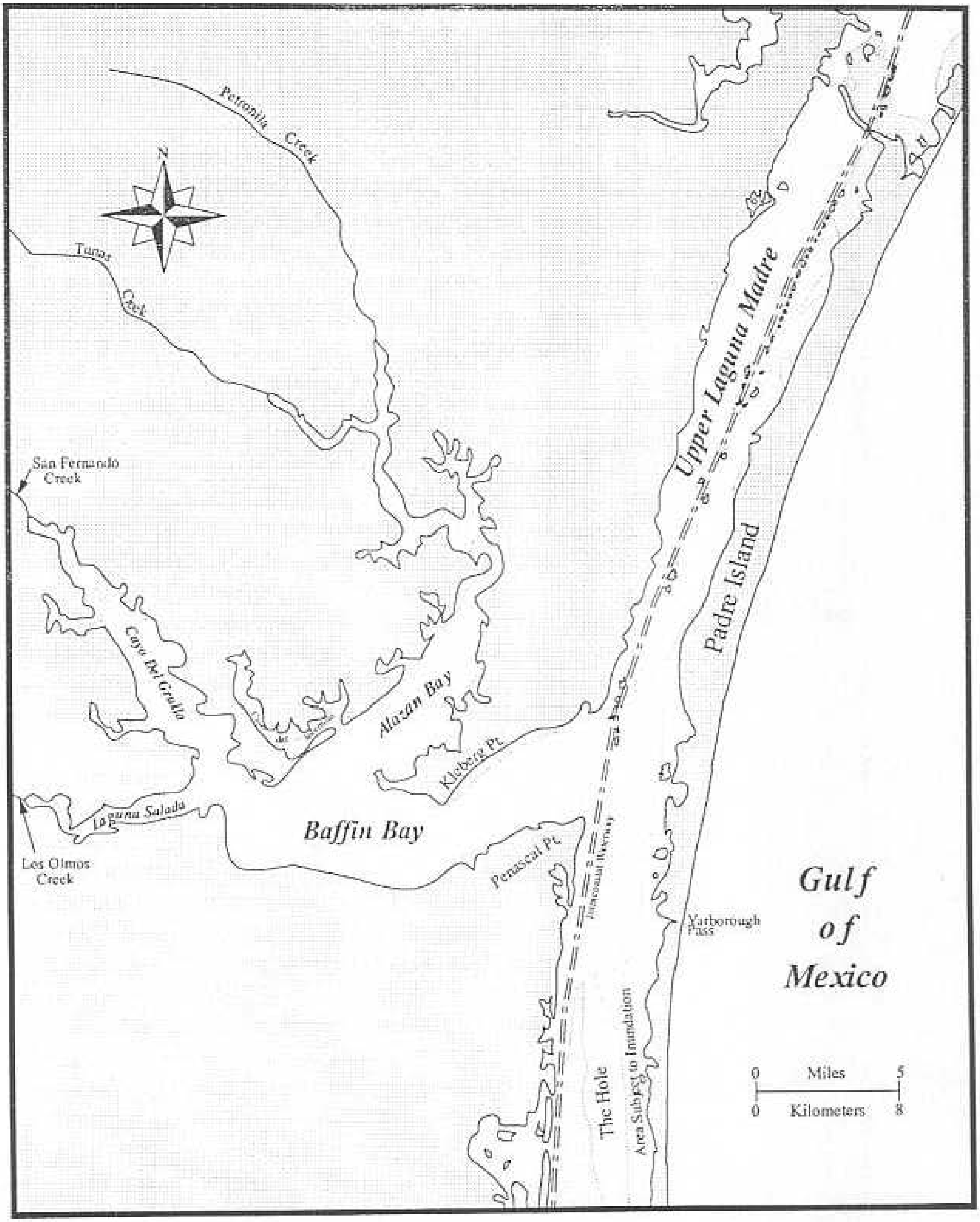

Fig. II.5. Upper Laguna Madre-Baffin Bay portion of CCBNEP study area.

true for the Baffin Bay-upper Laguna Madre system, because it usually is not measurably diluted with freshwater runoff and its connections to the open sea are remote (Aransas and Mansfield passes).

Alternatively, Emery and Stevenson (1957) define two types of estuaries based upon tidal and salinity features: (1) a normal or "positive" estuary and (2) an hypersaline or "negative" estuary. Characterized by upstream salinities lowered by adequate river inflow and mixing, the Mission-Aransas Estuary and Nueces Estuary are normal estuaries. The Baffin Bay-upper Laguna Madre system, however, is of the latter type, being characterized by arid climatic conditions, poor land runoff, limited tidal influence, and salinities routinely higher than those of the adjacent ocean.

B. Driving Forces and Human Influence

The principal driving forces that determine the habitat and community structure, as well as biological processes, in the CCBNEP estuaries are: (1) freshwater inflow; (2) basin physiography; (3) seasonal changes in nutrient supply and availability; (4) short- and long-term salinity fluctuations; (5) wind- influenced currents, tides, and sedimentological processes; (6) astronomical and seasonal tidal influences; and (7) hurricanes (Hayes, 1965; Morton and McGowen, 1980; Flint and Younk, 1983; Livingston, 1984; Armstrong, 1987; Montagna and Kalke, 1992).

Morton and McGowen (1980) review processes operating in Texas bays, noting that "bays are a transition between continental and marine environments". At times they are dominated by their associated fluvial systems, but during droughts, they become dominated by marine elements. Physical processes operating within the bays can be divided into two categories, those that are active daily throughout the year, such as tides, winds, waves, etc., and those that are seasonal and are of short duration, but high intensity, such as large winter storms or hurricanes (Morton and McGowen, 1980).

Human influences within the CCBNEP study area are greatest around the moderately populated and industrialized shores of the Nueces Estuary and to a lesser extent around the other two estuarine systems. In general, the local economy is based upon agriculture, ranching, oil and gas, sport and commercial fishing, and tourism (Diener, 1975; Brown et al., 1976, 1977; McGowen et al., 1976).

Initial priority problems (CCBNEP 1994a) or previously identified human influences (Diener, 1975) affecting living natural resources include:

1. reduced freshwater inflow
2. degradation of water quality
3. destruction or loss of wetlands and other critical habitats
4. altered estuarine circulation from channelization and disposal of dredge material
5. point source and non-point source pollution
6. bay debris
7. persistent brown tide and periodic red tides

Most of these issues will be addressed by specific work-projects during the Year-1 characterization phase of the CCBNEP. Ever increasing human population levels and uses of the estuaries will also be addressed during this time frame. The specific impact of these issues on the living resources within the CCBNEP study area are dealt with in Section 5 of this report.

C. Geologic History

The geomorphologic structures of most estuaries are ephemeral in terms of geological time. Climatological forces or factors are continuously at work shaping and reshaping the basin features. Characteristics of the present CCBNEP study area are dependent upon current and past interactions and linkages between upland drainages, the offshore marine system, and the dynamic geologic history of the Texas coast.

The environmental geology of the Texas coast has been uniquely and thoroughly characterized by the Bureau of Economic Geology (BEG), University of Texas at Austin. During a multi-year effort in the 1970's, this agency produced seven volumes entitled the *Environmental Geologic Atlas of the Texas Coastal Zone*. Each of the volumes, covering seven different areas of the coast, consist of a book and nine detailed maps. The text covers the geology, geologic history, climate, coastal processes, human impact, and information about each map. Maps include a large 1:125,000 scale map on the environmental geology of each area, and eight smaller maps at 1:250,000 scale covering: physical properties; environmental and biologic assemblages; current land use; mineral and energy resources; active processes; man-made features and water systems; rainfall, stream discharge, and surface salinity; and topography and bathymetry. This set of volumes and the follow-up *Submerged Lands of Texas* produced during the 1980's covering the same areas with detailed field sampling data provide Texas with possibly the best documented/characterized coastal zone in the United States. Three of these BEG volumes in each set cover the CCBNEP study area either all or in part: all of the Corpus Christi Area books (Brown et al., 1976; White et al., 1983), the southern part of the Port Lavaca Area (McGowen et al., 1976; White et al., 1989a), and the northern part of the Kingsville Area (Brown et al., 1977; White et al., 1989b).

The present Texas coastline is primarily a product of Pleistocene and Recent (i.e., Holocene, Modern) geologic history. The Pleistocene ice age included over one million years of complex glacial and interglacial climatic and sea-level changes (Brown et al., 1977; Fig. II.6A). It consisted of at least four major glacial episodes separated by warmer interglacial periods. Sea levels during the Pleistocene ranged from 91 - 137 m (300-450 ft.) lower than present during glaciation when water was trapped in great, continental ice sheets to near present levels during interglacial, warm periods (Brown et al., 1977).

One dominant physiographic feature within the CCBNEP study area formed during the late Pleistocene is an upland expression of former marine periods extending further inland. Although its origin is questioned, a large sand body approximately 4.8 km (3 mi) in width parallels the present coast along Encinal and Live Oak Peninsulas and Live Oak Ridge. These distinctive, exposed sand bodies, which can be seen in Flour Bluff, Ingleside, Fulton, and Aransas National Wildlife Refuge (ANWR), are thought to be either a former barrier island (Price, 1933) or barrier strand plain (Wilkinson et al., 1975).

Chronologically, beginning about 50,000 to 60,000 YBP (years before present), sea level began dropping during the final episodes of Wisconsin glaciation. The Pleistocene Nueces and other rivers entered the Gulf of México some 93 km (50 nautical miles) east of the present shoreline (Fig. II.6B and II.7A) and cut deep river valleys into older deposited sediments. About 18,000 YBP, sea level began to rise gradually as the last glaciation period diminished (Fig. II.6C). The lower reaches of river valleys began filling with sediments, but sea level rise exceeded sedimentation and lower portions of the valleys were drowned (Fig. II.7B) (LeBlanc and Hodgson, 1959; Brown et al., 1976).

About 4,500 YBP (end of Holocene, beginning of Modern time) when sea level was about 4.6 m (15 ft) below present, modern geologic processes became active. When sea level reached its approximate present level, 2,800 to 2,500 YBP, several natural changes began to occur: (1) the estuaries began to fill with sediment from eroding drowned river valley walls and deltaic sediments from rivers and streams, with oyster reefs, and with Gulf of México sediments via tidal inlets; (2) streams continued to erode the coastal plain headward; (3) offshore shoals slowly coalesced into barrier islands, restricting bays and lagoons landward; (4) coastal marshes, seagrass beds, and wind-tidal flats developed; and, (5) eolian erosion and deposition continued to modify the Modern barrier islands and the relict Ingleside (Pleistocene) barrier-strandplain (Fig. II.7C) (Brown et al., 1976).

D. Climate

The importance of climate on the composition and distribution of estuarine organisms and habitats cannot be overstated. Geologists and biologists have long recognized the importance of understanding effects of climate on geologic processes and biota respectively.

Within the CCBNEP study area wide variability in climatic conditions is the norm. Local citizens often state "the only thing predictable about our weather here is that it is unpredictable". Carr (1967) discusses the use of "climatological normals" or averages based on day-to-day or month-to-month calculations, but he strongly implies the tremendous year-to-year variations in unpredictable cycles are not revealed in those "normals". Data used to compute climatic averages of precipitation and temperature ("normals") include the extremes on either side of the averages, but the sometimes impressive day-to-day, season-to-season, and even year-to-year variations lie completely obscured or embedded in these averages (Carr, 1967).

Typically, the study area can be characterized as "a subhumid-to-semiarid east coast subtropical climate, with extreme variability in precipitation" with generally high humidity and infrequent but significant killing frosts (Fulbright et al., 1990). The CCBNEP study area mirrors on a small scale the north-to-south moist-to-dry gradient characteristic of the entire Texas coast (Brown et al., 1976, 1977; McGowen et al., 1976; Morton and McGowen, 1980). Generally, the area experiences high temperatures along with deficiencies in moisture, especially to the south. Major climatic influences are temperature, precipitation and evaporation, wind, and tropical storms or hurricanes.